5G SA Massive MIMO
SSB Optimization
Open RAN App

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Introduction

This white paper introduces a cutting-edge algorithm designed to optimize beam configurations within massive MIMO (mMIMO) systems operating in the Grid-of-Beams (GoB) mode. We'll show how this algorithm significantly boosts 5G coverage, capacity, and performance, particularly in densely populated urban environments with a mix of high and low-rise buildings. The algorithm's flexibility allows for dynamic adjustments in the number, shape, and tilt of beams-both horizontally and vertically – to precisely target user locations, adapting to variations across and within cells and over time.

During peak hours, beams can be directed more towards high office buildings, shifting focus towards residential areas in the evenings or weekends. Importantly, these adjustments aren't static; the algorithm responds to near real-time changes in traffic, user location, and signal quality, ensuring optimal beam configuration at all times.

The configuration of the GoB is at the heart of this approach, crucial for the initial access process as outlined in the Synchronization Signal Block (SSB) – the consistently only active signal in 5G New Radio (NR). The primary goal of this mMIMO SSB optimization is to determine the best SSB beam transmission setup, balancing coverage and user distribution across cell clusters.

This process is driven by a sophisticated mMIMO SSB optimization xApp, leveraging advanced AI techniques to merge initial access with dynamic beam adjustments in GoB mode. Our tests have demonstrated that this optimization can enhance subscriber Reference Signal Received Power (RSRP) by approximately 25% in specific environments, reflecting a significant improvement in the power a receiver measures over a particular communication channel.

Moreover, this algorithm supports operators in their quest for greater energy efficiency, aiding in the pursuit of net zero by refining beam-based NR SA coverage. Its utility extends to Open RAN deployments, where efficient beam management is crucial for matching or exceeding the performance of traditional RAN setups.

While currently focused on downlink communication, plans are in place to expand this application to uplink transmissions, promising further enhancements in capacity in the future.

Business and industry context

mMIMO stands at the forefront of 5G NR technology, which is poised to become a pivotal force in achieving the ambitious capacity and performance enhancements anticipated with 5G Advanced from 2024 onwards. The advent of new mMIMO technologies marks a significant leap in throughput, latency, and efficiency, largely due to the role of beamforming as a key enabler.

By improving spectral efficiency, mMIMO not only drives advancements in network performance but also plays a vital role in optimizing energy use. This efficiency is crucial for service providers aiming to manage costs effectively and meet stringent sustainability goals related to net carbon emissions. Beamforming enables base stations to direct signals precisely towards individual users, thereby minimizing the required transmission power.

While the potential of mMIMO is vast, it also introduces a spectrum of challenges that need to be navigated carefully throughout the remainder of the 5G era and beyond. Among these challenges, beam management emerges as a critical area of focus, particularly for innovators in the technology space such as Amdocs.

The issue of mMIMO beam management becomes even more pressing in the context of Open RAN. An increasing number of service providers are considering Open RAN to enhance network flexibility and reduce dependency on major equipment vendors. This shift towards Open RAN, often in conjunction with virtualized and cloud RAN architectures, underscores a move towards more distributed control and management of RAN operations, including the dynamic configuration of beams.

Effective beam management is therefore essential for delivering top-notch 5G performance, especially in densely populated macro environments. Mobile operators are particularly keen on ensuring that mMIMO capabilities within Open RAN frameworks achieve, if not surpass, the performance standards set by traditional integrated RAN systems, especially in terms of throughput, latency, and efficiency.

The significance of this technology is not lost on operators, especially those striving to offer enhanced data rates and Quality of Service (QoS) in densely populated areas. However, concerns remain among some operators about the capacity of virtualized baseband components in Open RAN systems, particularly regarding the open fronthaul interface between the baseband and the radio/ antenna elements. There's apprehension that these Open RAN components may not fully support the extensive processing demands of mMIMO network functions, including beamforming, potentially lagging behind the specialized capabilities of conventional base stations.

Contrary to these concerns, this white paper demonstrates the effectiveness of an advanced mMIMO optimization algorithm. This algorithm leverages open interfaces, seamlessly integrating into both commercial and open-source RAN Intelligent Controller (RIC) platforms, supporting the potential of Open RAN to support mMIMO functionalities.

The crucial role of optimization in Massive MIMO

The Amdocs-developed massive MIMO xApp focuses on optimizing coverage and capacity within the GoB MIMO mode. Each control beam, linked to a unique SSB, undergoes optimization in terms of shape and spatial distribution. This optimization utilizes sophisticated algorithms that take into account signal quality, traffic volume, and user location.

In the domain of 5G beamforming, GoB is a key strategy, characterized by its pre-configured beam and grid setup. This contrasts with the digital or Eigenvalue-based approach, which relies on User Equipment (UE) sending Sounding Reference Signals (SRSs) in the uplink. These signals, upon reaching the gNodeB (base station), inform the calculation of optimal signal weights for downlink transmission. This dynamic adjustment enables the system to track UEs, allowing for beam adaptation to device movements, which in turn enhances network efficiency and performance.

Conversely, the GoB method employs predefined beams with fixed weights, all stored within the base station. When signals are sent downlink to a UE, the UE assesses and reports back on which beams provide the strongest signal, based on received power. This feedback, sent via the uplink to the base station, facilitates the selection of the most effective beams without the need for constant, dynamic weight recalculations at the base station level.

This approach reduces computational demands on the base station, as it sidesteps the need for ongoing recalibration of beam weights. With GoB, the focus is on selecting the best beams from a set roster, a process that is key to enhancing network performance and capacity.

Understanding 5G SSB technology

Radio access

In cellular networks, transmissions are categorized into two main types: control and user traffic. Control channel transmissions, essential for network coordination, are optimized for each cell, varying in time and frequency across the mobile network, yet are uniform for all users within a particular cell. On the other hand, traffic channel transmissions are distinct for each User Equipment (UE), differentiated by space, time, and/or frequency, barring multicast or broadcast situations.

At the cell level, one critical application of control channel transmissions is the initial radio access procedure. In this phase, newly arrived UEs identify the most suitable cell for entering the mobile network. Each cell broadcasts control channels containing initial details about the network and its status, aiding UEs in establishing a connection to the network.

This process, known as cell search and selection, involves UEs scanning radio frequencies listed on their SIM cards to find control channel signals from cells affiliated with the operator's network. The search focuses on evaluating the signal quality of these control channels, with UEs measuring metrics like the RSRP and/or the Received Signal Strength Indicator (RSSI). Cells that surpass specific RSRP and/or RSSI thresholds are chosen. Subsequently, using initial data such as the Physical Cell Identifier (PCI) and the Primary and Secondary Synchronization Signals (PSS/SSS), the UE progresses through the initial access procedure. This includes initiating a random access procedure, followed by the network attachment process.

Prior to the implementation of 5G (NR) Standalone (SA), the transmission of control channels and the initial access process were characterized by sectorized coverage. For a UE to detect a cell's control channel, it needed to be broadcast within a designated area where its RSRP and/or RSSI exceeded certain RF signal strength thresholds. Typically, this coverage area, delineated by sectorized antennas, spanned 120° in azimuth, as illustrated in Figure 1.

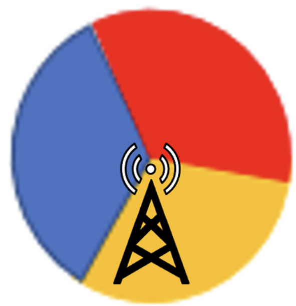

Fig. 1: Site with three sectorized cells, each covering 120° (top view)

An example of a planning scenario under this setup is depicted in Figure 2, showcasing the strategic deployment of sectorized coverage in cellular networks before the transition to 5G NR SA.

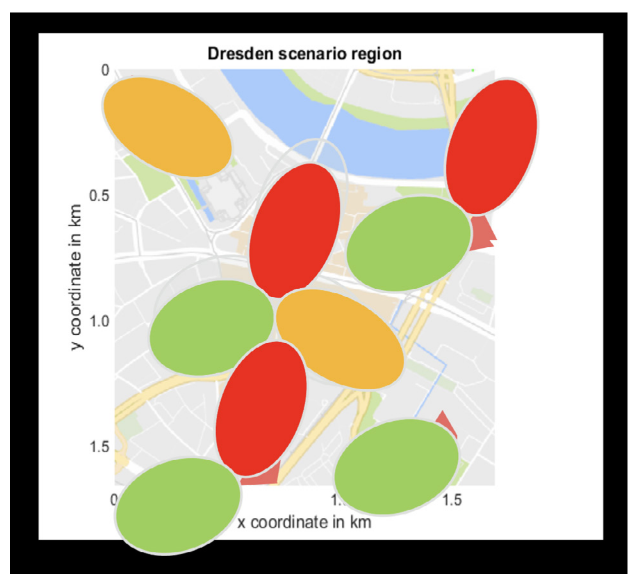

Fig. 2: Sample planning scenario with sectorized cells

In cellular network deployments, antenna configuration – covering type, azimuth, and tilt – is strategically optimized through Coverage and Capacity Optimization (CCO) before launch. This pre-launch step is pivotal for network efficacy. Specifically, adjusting an antenna's tilt significantly affects its coverage area, a critical factor for network reach and service quality. Figure 3 illustrates the impact of tilt adjustments on the coverage of a sectorized antenna, demonstrating the nuanced considerations involved in optimizing network performance.

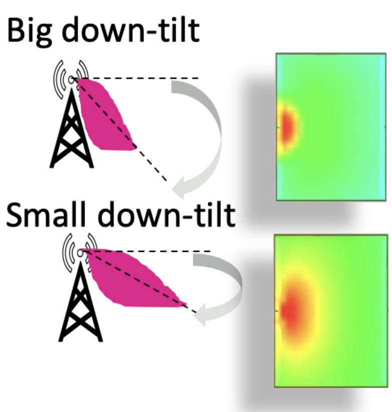

Fig. 3: Impact of antenna tilt adjustments on sector antenna coverage area

Beam-based Coverage in 5G/NR control channel transmission

5G New Radio NR SA represents a significant transformation in cellular technology with its mandatory beam-based air interface, setting it apart from previous generations. This advancement raises questions about its implications at the air interface level, particularly during initial access phases.

The transition to 5G necessitates more sophisticated antenna hardware capable of beamforming. Unlike the traditional 120° sectorized antennas, 5G employs MIMO antenna panels. These panels can be extensive, supporting the formation of multiple directive beams, a cornerstone of the 5G beam-based air interface. Control channels in this setup are transmitted via SSBs.

An SSB is composed of the Primary Synchronization Channel (PSS), the Secondary Synchronization Channel (SSS), and the Physical Broadcast Channel (PBCH). These blocks are arranged into SSB burst sets, transmitted in a default 20ms cycle, which can be adjusted for timing. To align with the beam-based approach to initial access, each SSB in a burst set may be transmitted using a different spatial beam. Figure 4 illustrates this concept with L=8 SSB beams, utilizing an Orthogonal Frequency Division Multiplexing (OFDM) subcarrier spacing of 15 kHz numerology.

The 3GPP standard specifies up to 4 SSB beams for frequencies below 3 GHz, up to 8 beams for sub-6 GHz frequencies (Frequency Range 1 – FR1), and as many as 64 beams for millimeter Wave (Frequency Range 2 – FR2) frequencies above 6 GHz. In this beam-based paradigm, the coverage area of a cell is defined by the aggregate of all SSB beams emitted from the cell's MIMO antenna, marking a significant evolution in how cell coverage is conceptualized and delivered in 5G networks.

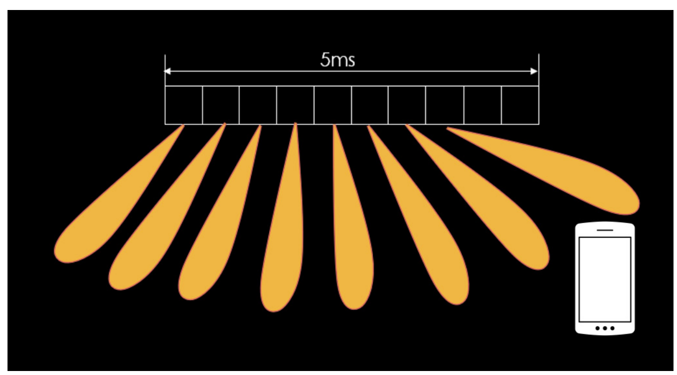

Fig. 4: SSB Burst Set Example

Figure 5 depicts a site comprising three cells, each characterized by four horizontal beams. Compare this with Figure 1, which illustrates the traditional sectorized cell approach.

Fig. 5: A site with three cells, each cell being defined by four SSB beams, view from top

Figure 6 presents a sample planning scenario using horizontal SSB beams, in contrast to the sectorized cell approach shown in Figure 2.

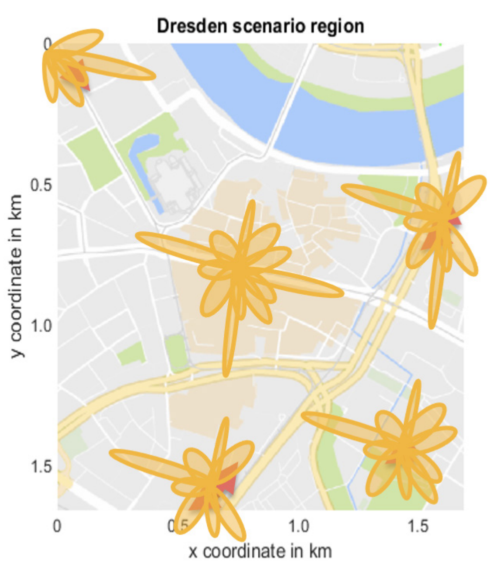

Fig. 6: Sample planning scenario with SSB beams.

Figure 7 illustrates an example of three vertical SSB beams.

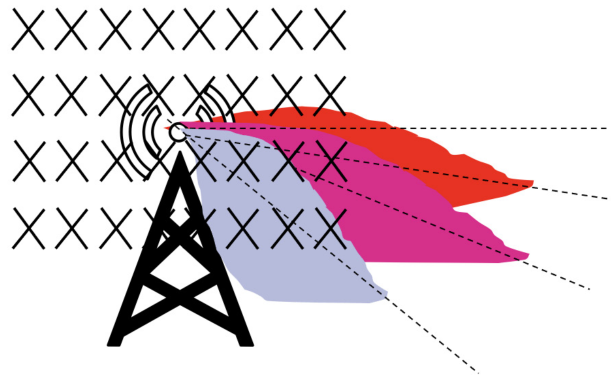

Fig. 7: Massive MIMO antenna panel defining three vertical SSB beams

Importantly, the standards above do not dictate the vertical and horizontal distribution or the shape of each beam. This flexibility allows the configuration of cell-defining SSB beams – both vertically and horizontally – to be tailored based on factors like inter-site distance, three-dimensional traffic distribution, and environmental considerations, including the surrounding buildings within the coverage area.

Optimizing SSB beams for enhanced performance

The aim of the massive MIMO SSB optimization use case is to pinpoint the ideal SSB beam transmission setup for optimal coverage and user distribution across a cell cluster. The focus of the mMIMO SSB optimization xApp is primarily on enhancing coverage within a cell cluster utilizing the GoB MIMO operation in idle mode, which employs static beamforming.

When GoB MIMO operation mode extends to CSI-RS (Channel State Information-Reference Signals) beam transmission configuration in connected mode – such as in FR2 (Frequency Range 2) with analog or hybrid beamforming – the use case also targets capacity optimization within the cell cluster.

Application use case

This use case determines the best beam configuration considering the number of SSB beams, beam width, and beam boresight direction both horizontally and vertically. If the O-RU (Open Radio Unit) vendor has predefined beam groups, choosing the best beam group becomes one of the use case's goals.

For illustration, Figure 8 showcases two distinct preconfigured SSB beam groups stored in the massive MIMO antenna panel. The use case entails selecting between beam group-1 (red – four horizontal beams) and beam group-2 (yellow – eight horizontal beams), based on which provides superior coverage KPI (Reference Signal Received Power - RSRP).

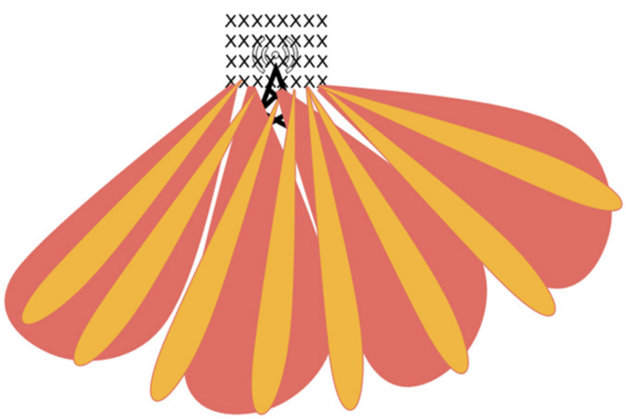

Fig. 8: Massive MIMO antenna panel with two different pre-configured beam groups

This use case incorporates traffic predictions, user locations, and signal quality metrics to dynamically refine the SSB transmission by adjusting the GoB used during the initial access procedure. The GoB outlines the beams' horizontal and vertical reach, shaping the beam and its coverage area. The optimization process involves selecting from available pre-configured beam groups and, where possible, fine-tuning individual beams' tilt, azimuth, and width, along with their quantity, leading to recommendations for new optimized beam groups.

Optimization targets SSB coverage enhancement across a cell cluster, addressing mutual dependencies rather than focusing on individual cells. Adjustments in panel tilt and azimuth (Coverage and Capacity Optimization - CCO) can be considered in addition, otherwise the current state will be noted. The exploration of uplink SRS channel estimation and beam-specific transmission powers is earmarked for future study and expansion. The anticipated outcome of this algorithm is an improvement in SSB coverage within the 3D geographical service area of a cell cluster, with significant benefits in densely populated urban settings featuring varied and tall buildings. Comparing Figures 9 and 10, we see a before-and-after scenario of SSB optimization, demonstrating the elimination of coverage gaps through the employment of alternate beam groups with varied beam tilts.

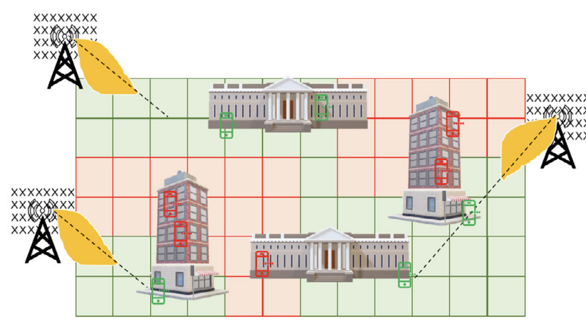

Fig. 9: Massive MIMO network before SSB optimization

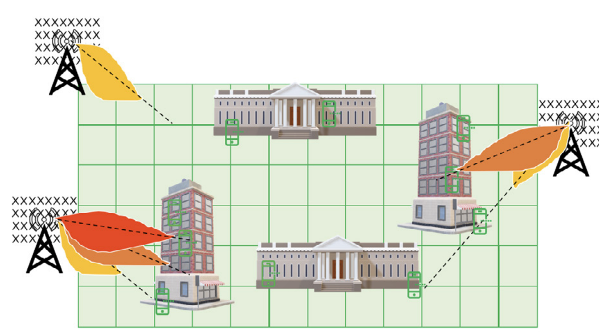

Fig. 10: Massive MIMO network following SSB optimization

In the initial scenario, prior to SSB optimization, coverage gaps are particularly evident on the upper floors of high-rise buildings. This issue stems from the default configuration of a beam group that employs a singular beam tilt within the group, making the lack of coverage conspicuous. Following the SSB optimization, which involves switching to beam groups equipped with beams of varying tilts, these coverage gaps are effectively addressed and resolved.

Architecting the optimization application

The massive MIMO SSB optimization algorithm is encapsulated within a xApp, hosted in a Docker container for deployment flexibility. This xApp is designed to integrate seamlessly with both commercial and open-source near-real-time RIC platforms through their open RIC App SDK. It accesses RAN telemetry data – such as Configuration Management (CM), Performance Management (PM), and User Equipment (UE) measurements/Minimization of Drive Tests (MDT) traces – via the Open RAN standardized O1 and E2 interfaces. Additionally, for configuring the massive MIMO antenna panel, the xApp requires read and write access through the O-FH-m interface, a standard in Open RAN architecture, as depicted in Figure 11.

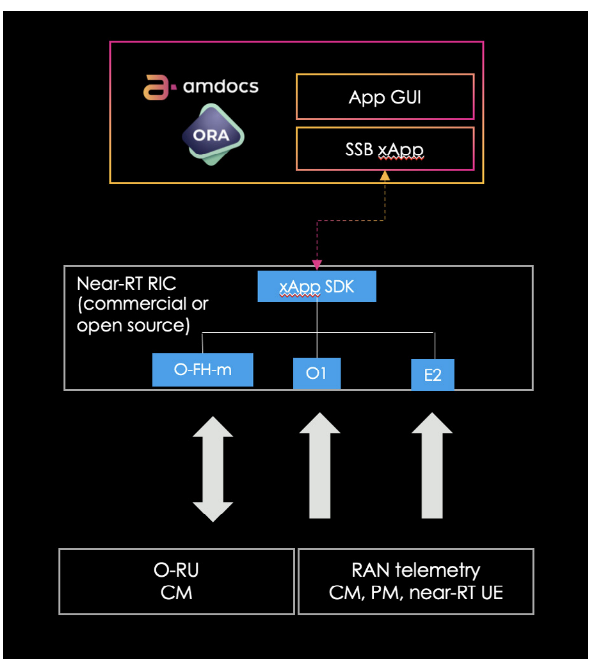

Fig. 11: SSB xApp Architecture

The application features a web-based Graphical User Interface (GUI) that enables users to adjust algorithm policy settings, including the target function for the optimizer and the coverage threshold, as illustrated in Figure 12.

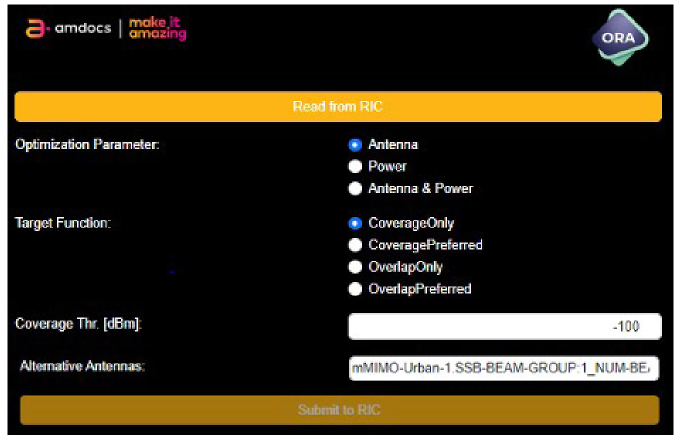

Fig. 12: SSB xApp Policy GUI Illustrative Optimization example

Our verification of the SSB optimization algorithm was conducted using a dynamic NR 5G SA cellular network simulator. This simulator modeled a network with twelve sites, each comprising three sectors at 0, 120, and 240 degrees azimuth, equipped with 32x32TxRx massive MIMO antenna panels at 35 meters height, and transmitting at 33 dBm in the 5G n77 frequency band at 3.7 GHz. The simulated environment included six randomly placed high-rise buildings, with heights ranging from 10m to 50m, using the 3GPP 38.901 Urban Macro (UMa) propagation model. UE positions were randomly assigned within this space, including varied heights to simulate different building floors.

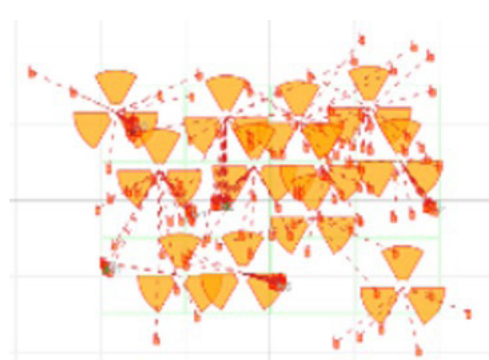

Figure 13: Simulation area setup.

For this evaluation, coverage served as the primary KPI. The methodology involved dividing the entire simulation area into spatial bins with dimensions of 50x50x5 meters. Given the total area of 10 km² and a vertical range of 50m, this resulted in 400,000 spatial bins. Approximately 10% of these bins contained User Equipment (UE) positions, selected randomly. The exercise entailed collecting RSRP measurements from UEs within each bin, averaging these measurements, and then comparing the average to a coverage threshold of -100 dBm RSRP. Bins with an average UE measurement exceeding this threshold were considered to have coverage, whereas those below were deemed to lack coverage.

The simulations commenced with all massive MIMO panels configured to an initial GoB beam group 1 setup. This configuration included four horizontal beams, each with a 30-degree beamwidth and a collective (sum over panel and beam tilt) down-tilt of 7 degrees. These beams were directed at azimuth angles of -45, -15, 15, and 45 degrees relative to the panel's azimuth, as depicted in Figure 14.

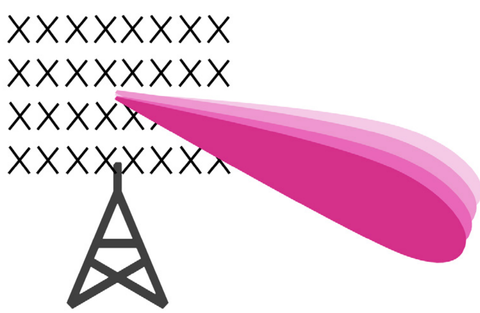

Fig. 14: Beam group 1

In the initial, non-optimized setup, coverage gaps were notably present on the upper floors of high-rise buildings, a consequence of beam group 1's singular tilt setting. This group consisted solely of beams angled in one direction, leading to insufficient coverage in areas positioned at higher elevations, as illustrated earlier in Figure 9.

To address this, an alternative beam group, labeled as beam group 2, was available within the massive MIMO antenna panels. This group featured eight horizontal beams, each with a 30-degree beamwidth. Half of these beams were set with a 7-degree down-tilt, akin to those in beam group 1, while the remaining four beams were adjusted to a more shallow 1-degree down-tilt. This configuration allowed for beams to be directed at -45, -15, 15, and 45 degrees azimuth, similar to beam group 1, but with the added flexibility of two tilt angles to better address coverage needs at varying heights. Figure 15 provides a visual representation of this configuration.

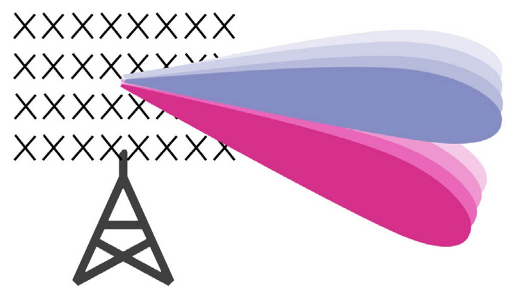

Fig. 15: Beam group 2

Following the initial simulation where each massive MIMO panel was set to beam group 1 and after gathering adequate RSRP data, the SSB optimization algorithm was activated. The algorithm's goal was to maximize the number of spatial bins achieving coverage by selecting the most effective beam group for each cell, based on the potential for improved overall coverage across the cell cluster.

The SSB optimization process focuses on evaluating and potentially altering the SSB GoB beam groups. It selects the appropriate SSB GoB beam group for each massive MIMO panel, aiming to maximize the count of spatial bins that surpass a -100 dBm coverage threshold across the entire cluster. In this specific scenario, the optimizer switched from beam group 1 to beam group 2 in nine out of the thirty-six cells. Beam group 2, with its beams set at lower tilts, was able to extend coverage to higher floors within the buildings.

Prior to optimization, 59% of spatial bins with UE measurements within the simulation area met the coverage criteria, indicating significant scope for enhancement. Following the application of changes to the antenna beam groups, the proportion of bins with sufficient coverage rose to 74%, marking a substantial 25% improvement in cell coverage through the massive MIMO SSB optimization process alone. It's worth noting that incorporating traditional CCO strategies – adjusting antenna panel tilt, azimuth, and transmission power – could potentially raise overall coverage by an additional 10-15%, a typical outcome of pre-launch CCO efforts. However, this simulation was specifically designed to showcase the efficacy of the massive MIMO SSB optimization algorithm.

Figure 16 presents a histogram that captures the beam-level RSRP enhancements in increments of 10 dB, both before and after the SSB optimization. The visualization clearly demonstrates a significant increase in the number of covered spatial bins post-optimization, underscoring the algorithm's effectiveness in enhancing network coverage.

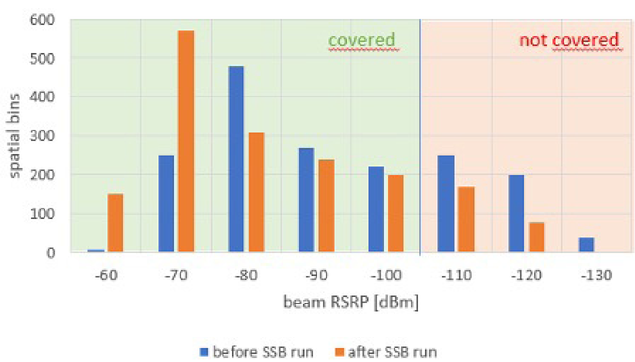

Fig 16: Beam-level RSRP Histogram before and after SSB optimization.

This example focused on enhancing coverage, as measured by RSRP, through changes to SSB antenna beam groups. To evaluate the SSB xApp's impact, we compiled a histogram detailing the count of spatial bins within specific RSRP intervals, in 10 dB increments. The optimization aimed for an RSRP threshold of -100 dBm. We compared the quantity of bins exceeding this threshold to the total number of bins meeting this criterion in the UE measurements collected from the simulated network, both before and after optimization. Post-optimization, there was a notable increase in the bins surpassing the coverage threshold, as illustrated earlier in Figure 16.

Conclusion and future directions

Massive MIMO emerges as a foundational element of 5G NR SA, introducing a beam-based air interface that revolutionizes initial access protocols through SSB. The adoption of Grid-of-Beams (GoB) beamforming necessitates a sophisticated optimization of beam characteristics – number, shape, and boresights – to ensure they are in harmony with urban layouts, traffic distribution, and RF propagation conditions. This task grows in complexity within cell clusters, where interdependencies between cells introduce additional layers of complexity, underscoring the indispensable role of artificial intelligence (AI) in navigating these challenges.

This paper has unveiled an advanced AI algorithm that significantly advances the optimization of beam configurations in the GoB mode, showcasing notable improvements in coverage, capacity, and performance, especially within urban environments. The deployment of this algorithm as an Open RAN xApp, with its compatibility across a spectrum of RIC platforms and its utilization of standard interfaces for RAN telemetry, represents a leap forward in network management flexibility and efficiency.The contributions of this algorithm extend beyond mere technical enhancements; they embody a strategic approach to network optimization, including:

- The selection from and refinement of beam groups to suit dynamic urban and traffic conditions
- The adept management of beam configurations to cater to specific network demands, and
- The integration of comprehensive RAN telemetry to inform real-time adjustments.

There is a promising avenue for further elevating network performance by aligning this algorithm with traditional CCO methodologies, suggesting a synergistic pathway to achieving unparalleled network efficiency and user experience.

Anticipating future advancements, this technology's scope for expansion includes the integration of uplink telemetry, such as Sounding Reference Signals (SRS), and the fine-tuning of CSI-RS GoB traffic beams and beam-specific power settings in fully digitalized massive MIMO antenna systems as well as a possible re-interfacing towards the Open RAN R1 interface to serve as a non-real-time rApp. These prospective developments hint at an even broader spectrum of optimization capabilities, poised to redefine the benchmarks of 5G network performance.

The acknowledgment of this solution by the Telecom Infra Project (TIP)underscores its impactful contribution to the 5G technological landscape, setting a precedent for future innovations in the field.

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Abbreviations

CCO	Coverage and Capacity Optimization
CM	Configuration Management
CSI-RS	Channel State Information Reference Signal
FR	Frequency Range
GoB	Grid-of-Beams
GUI	Graphical User Interface
MDT	Minimization of Drive Tests
MIMO	Multiple Input Multiple Output
mMIMO	massive MIMO
NR	New Radio
OFDM	Orthogonal Frequency Division Multiplexing
PBCH	Physical Broadcast Channel
PCI	Physical Cell Identifier
PM	Performance Management
PSS	Primary Synchronization Channel
QoS	Quality of Service
RAN	Radio Access Network
rApp	Application on a non-real-time RIC
RIC	RAN Intelligent Controller
RSRP	Reference Signal Received Power
RSSI	Received Signal Strength Indicator
SA	stand-alone
SRS	Sounding Reference Signal
SSB	Synchronization Signal Block
SSS	Secondary Synchronization Channel
UE	User Equipment
UMa	Urban Macro
xApp	Application on a near-real-time RIC

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